*Francisco Oyague,*
*NREL*

# SIMPACK in the NREL Gearbox Reliability Collaborative

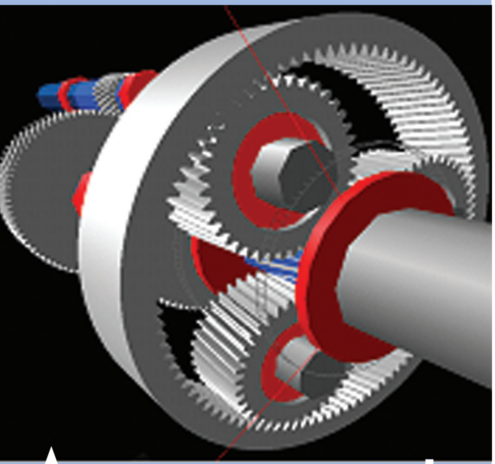

*Fig. 1: Drive-train Analysis and Modelling*

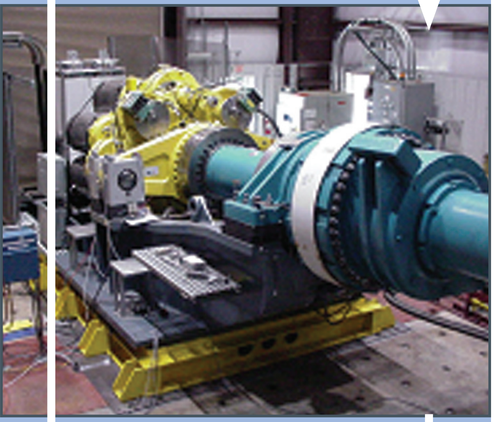

*Fig. 2: Full scale Dynamometer testing*

*Fig. 3: Field Testing*

**With the growing consciousness of global climate change, the importance of renewable energy has become paramount. The wind industry in particular has seen an unquenchable demand as a result, and the need for reliable and affordable wind turbines has become all the more apparent. Unfortunately, recurrent drive train failures have plagued the industry and have prevented the turbines from achieving their intended 20 year design life.**

**The component most responsible for downtime is the gearbox. Furthermore, gearbox replacement and lubrication account for 38% of the parts cost for the entire turbine system. This calls for the implementation of new and advanced simulation techniques to be integrated into the gearbox design process so that they can meet their design life.**

## NREL

The National Renewable Energy Laboratory (NREL) is the USA's primary laboratory for renewable energy and energy efficiency research and development (R&D). The National Wind Technology Center (NWTC), which is a subdivision of (NREL), is devoted to the research and development of wind energy. This entity has embarked on the difficult task of revealing the causes and loading conditions that result in the premature failure of the gearboxes.

The NWTC approaches the problem by bringing together the different parties involved in the gearbox design process with the common goal of the improvement of the lifetime of gearboxes. It achieves this with a Gearbox Reliability Collaborative (GRC). The collaboration is attempting to include turbine owner/operators, gearbox manufacturers, bearing manufacturers, lubrication companies, and wind turbine manufacturers. With the NWTC as a mediator, it is insured that proprietary information among these different branches will not be disclosed.

In addition to the cooperation of the previously mentioned parties, the GRC seeks to achieve its goal by exploring three avenues of research. These include: drive train numerical analysis and modeling, full-scale dynamometer testing, and field testing.

These different branches will be correlated and iterated to obtain the closest representation of actual load behavior in a controlled environment.

## THE BASELINE MODEL

The GRC seeks to develop a model that is representative of the current standards in the industry, and that can be extrapolated to a large number of turbines with different sizes and dimensions but with the same configuration. Therefore, the analysis and experimentation is performed on a carefully selected already existing machine with significant operating history. This approach assures that the information revealed by the testing and analysis will be more valuable and relevant to the current industry.

The approach also seeks to integrate into the drive train design process several numerical models which capture the dynamical nature of the drive train. These dynamical models build progressively in complexity, and aim to reveal new insight into the internal forces inherent to the dynamical behavior of the drive train.

Additionally, the progressive nature of these models will offer a method of validation by comparing models of less complexity to models of higher complexity, thus eliminating error in the model development. Moreover, these models will allow for the filtration of sensitive information between the different parties of the design process, therefore, ultimately increasing the transparency of the design process.

## THE PROGRESSIVE MODEL

SIMPACK plays an important part in the numerical analysis and simulation of the GRC especially with respect to the development of the progressive gearbox models.

The first model developed is a simple two-mass torsional vibration system in which one mass represents the rotor and another mass represents the generator. The entire drive train is represented by a torsional spring damper connection. This is the simplest form in which the drive train can be simulated. This rudimentary approach is used by many aero-elastic simulation codes.

The second model looks at the torsional compliances of every individual stage of the gearbox, as well as, each individual shaft. It is also able to account for changes in torque and angular velocities generated by the gearbox.

The overall response of the drive train should be similar to the response observed in the first model, although this model will give a much closer representation of the torsional behavior of the gearbox. The third model implements gear elements that are to account for backlash gear tooth contact and changes in center distances, among others. The joints in this model are of a single degree of freedom allowing only rotation, thus neglecting the compliances and clearance contribution of the bearings.

The fourth model adds degrees of freedom to the joints which are constrained by the use of force elements that represent the stiffness of the bearings. This model gives better representation of bearing load distribution, as well as, gear miss-alignment. These models are the first step to the development of a fully coupled model. A fully coupled model is required due to the reciprocal characteristics of the interactions among the dynamical components of the wind turbine.

## LOAD GENERATION AND SIMPACK

With the implementation of the aero-elastic software FAST_AD, relevant load cases such as braking maneuvers, fault loads cases and turbulent conditions were generated. The load cases were imported into the SIMPACK progressive models to run a number of simulations.

The integration of these two powerful tools resulted in progressive comprehensive models that are capable of generating load cases for the individual components of the drive train. Ideally, these load cases should be integrated into the standard gearbox design process, as it typically does not fully account for the dynamical behavior of the individual components of the drive train.

Additionally, the models were compared to each other from least to most complexity in order to identify the level of detail and fidelity that each model was capable of generating. This comparison made clear the capabilities of the models, as well as, the possibility of implementing them into the gearbox design process to mitigate the information barrier existing between manufacturer and providers.

The comparison information can also be used by the gearbox designer to select the drive train model complexity that is most appropriate for an individual task.

## FUTURE WORK

Future analytical work will include the development of a fully coupled model that will capture the dynamical behavior of the different components of the turbine.

In addition, the models will undergo a broad range of loading conditions in an attempt to reveal driving loads that may not be taken into consideration in the designs process.

Highly instrumented gearboxes in the dynamometer, as well as in the field, will be used to validate the behavior of the internal components simulated in the models.

Detailed finite element analysis of the gearbox will be performed so that the loading conditions of the internal components generated by SIMPACK could be better correlated to failure modes observed.

SIMPACK will also be used to generate a dynamical model of the dynamometer so that the loads that it generates will better resemble the loads recorded from the field.

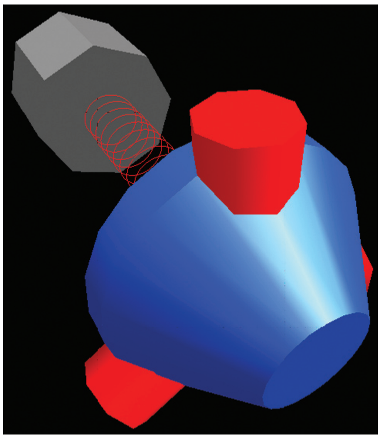

*Fig. 4: First Model Stage*

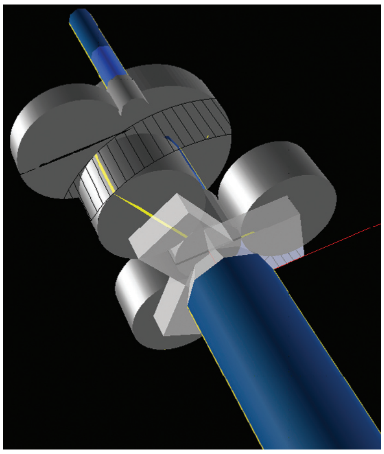

*Fig. 5: Second Model Stage*